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ON A BASIC ROCK DERIVED FROM GRANITE

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ON A BASIC ROCK DERIVED FROM GRANITE.

WHILE studying the hematite deposits of St. Lawrence and Jefferson counties, New York, under the direction of Dr. James Hall, State Geologist, the writer had occasion to examine some interesting rocks associated with the ores, which are worthy of note.

A brief description of the rocks is given in the report on the region presented to Dr. Hall, in which especial attention is paid to their relation to the problem of the origin of the iron ores. The aim of the present paper is to supplement that report with a more complete account of one phase of these rocks, occurring at the Old Sterling mine, in Antwerp, Jefferson county.

Mode of occurrence of the rock.—The mine consists of a large open pit, together with considerable underground workings. The surface rock is Potsdam sandstone, beneath which the ore, a red hematite, occurs in large irregular masses, intimately associated with a rock of entirely different character, which is the subject of this paper. The contact between this rock and the ore is extremely irregular, as is well shown in the open pit where the ore has been removed leaving the rock in projecting knobs, ridges, and walls, with intervening pockets and hollows. In the underground workings it is not uncommon for the ore to be suddenly cut off by the rock and to appear again after passing through a greater or less thickness of it. The contact is evidently irruptive and is precisely like the contacts of granite and limestone which are common in the region, although the rocks involved have a very different appearance. Emmons,[1] who has given the only detailed account of the ore and associated rock, considered them both igneous, and called the rock serpentine, a name which has clung to it ever since. The facts adduced by Emmons

[1] Geology of New York. Second District, p. 97.

to prove the igneous nature of the rocks were hardly of a character to justify the conclusion, and that he was right in regard to the so-called serpentine must be regarded as a mere matter of chance.

Description of the rock.—A hasty examination of many specimens of the rock would seem to warrant Emmons' determination of it as serpentine. It is dark green or black, massive, and very fine grained or quite aphanitic, with rather waxy lustre, and abundantly slickensided. Thus far it is precisely like serpentine, and many specimens show no other prominent features. But most of the rock is mottled with abundant white, vitreous spots, of extremely variable size. Where these are large enough to be clearly seen (and they may reach three or four inches in diameter), it is evident that they are fragments of quartz. Specimens in which the grains are small and evenly distributed closely resemble a porphyritic rock with glassy or aphanitic groundmass. In the presence of this quartz, there is a marked divergence from the ordinary character of serpentine.

The slickensides which are so abundant in hand specimens are developed on a large scale in the rock exposed in the mine pit. They run in every direction, and on this account most of the exposed surfaces are slickensided, being, as a rule, curved and showing a beautiful polish. Such surfaces measuring more than one hundred square feet are not uncommon. A good example appears in the centre of the pit upon a dome-like mass of rock.

Origin of the rock.—Accepting the evidence afforded by the contact, that the rock must be igneous, a difficulty is met at once in its apparently contradictory features. Its serpentinous aspect suggests derivation from a basic rock, but conflicting with such a supposition is the presence of much quartz. This mineral is, moreover, so distributed that it cannot be accounted for as inclusions, or, to any great extent, as secondary. These facts, noted in the field, led the writer to a close examination of the exposures in the hope of finding some portion of the rock which, through less complete alteration, would give some clue to

its origin. The examination resulted in the finding of several small patches, which, though considerably altered, still retain enough of their original character to show conclusively that they are granite. The transition between the fairly fresh granite and the serpentine-like rock is very gradual, the feldspar losing its fresh appearance and passing over into a green aggregate, while the quartz decreases in quantity, till in some specimens it is wholly lacking. To the naked eye no other minerals are visible, the original granite having been a coarse, pegmatitic variety.

The alteration of an acid granite into a nearly black, apparently basic, rock is an exceptional phenomenon, and yet in this instance the field evidence alone is of such conclusive nature that there can be no doubt that such is the case. Furthermore, the operation has taken place on a large scale, for there are hundreds of tons of the altered rock in sight, and it is impossible to tell how much is underground.

Additional evidence that the rock is an alteration of granite is afforded by the fact that at the bottom of the underground workings the ore rests upon a granite which differs only in freshness from the material of the least altered patches in the serpentine. But even this granite shows the beginnings of the alteration.

Megascopical aspect of the alteration.—A specimen of granite from the bottom of the shaft is a decidedly coarse-grained rock, made up of quartz and feldspar, the latter predominating. Besides these distinct minerals there is a limited amount of greenish material which fills the interstices between the essential minerals. The latter have very irregular outlines, the feldspar occurring in decidedly larger individuals than the quartz. The former mineral generally has bright cleavage faces; less often they are dull and earthy. The color is gray with a very faint pink tinge. The quartz is colorless and clear, with the usual vitreous lustre.

The granite of the least altered patches in the "serpentine" differs from such a specimen in having a larger amount of the

green aggregate, and in the color of the feldspar. This color is a decided pink or red, but there can be no doubt that it is itself a result of alteration, having replaced an original gray like that of the feldspar of the specimens from greater depth. These patches of comparatively little altered granite are only a few feet in diameter, and shade off into the typical serpentine-like rock on all sides. The passage is gradual as a whole, but more rapid in some spots than in others, so that, while it is impossible to draw any line of demarcation in the stages of the process, lines uniting equally altered portions around a granite core would be extremely irregular.

From the centre of such a core outward the green aggregate increases, while the feldspar gradually disappears, till finally there remains a waxy, deep green mass holding fragments of quartz. In some highly altered specimens the quartz is very conspicuous against the dark groundmass; in others it is entirely absent, though this is never true of large masses. In still other cases lumps of quartz several inches in diameter occur. These always lie close to one another and usually along definite zones, showing clearly that they are fragments of crushed veins.

In the slightly altered granite cores there are no conspicuous indications of disturbances, the slickensides being confined to the highly altered phases of the rock, in which, as stated above, they are very prominent. This fact, together with the great irregularity in the direction of the slickensides, suggests that the movements which have formed the polished surfaces may have resulted from changes of bulk in the rock attendant upon the alteration, as in the case of true serpentines.[1]

It should be noted, however, that the granite cores are so small that they might fail to give evidence of considerable movements in the mass as a whole, and such movements may account for the slickensides, as they do for the crushing of the quartz in veins and scattered through the rock. That the latter

[1] J. S. Diller, Geology of the Lassen Peak District, 8th Ann. Rept., U. S. G. S.' p. 401.

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is the case is clearly shown by the microscopic structure of the rock, as stated below.

Microscopical details of the alteration.—A microscopical examination of sections illustrating all of the phases of alteration shows some variation in the intermediate stages of the process, but considerable uniformity in the final results.

Sections of the least altered granite show it to consist of orthoclase, microcline, and quartz, with occasional stout prisms of apatite and irregular masses of tourmaline. Granite of this character is quite common in the region, and has been previously described by the writer.[1] The feldspar has the common dull and cloudy appearance. The quartz contains abundant fluid inclusions and great numbers of the hair-like bodies usually considered rutile. Undulatory extinction is constant, and much granulation is shown in nearly all sections.

Alteration begins with the development of a greenish aggregate in the feldspar. This may form irregular masses, or may be confined to cracks. Very often quite large portions of the aggregate have angular outlines formed by cleavage cracks of the feldspar. Where the aggregate has formed in a zone of crushing, it usually contains small, angular fragments of feldspar which at first sight look like crystals of some newly formed mineral. The areas of the aggregate are very unequally distributed in the granite, one portion of a specimen being greatly changed, while another portion remains unaltered. In some cases this is clearly due to the arrangement of cracks and crushed zones, but often there is no apparent reason for it. As the alteration proceeds the areas of the aggregate gradually extend until they entirely replace the feldspar, leaving no trace of its former presence.

At the same time the quartz is attacked, but, as a rule, it yields much more slowly than the feldspar. In the absence of cleavage the alteration proceeds along the borders of the grains and in the irregular cracks. The areas of alteration product

[1] C. H. SMYTH, JR.: Petrography of the Gneisses of the Town of Gouverneur, N. Y. Trans. N. Y. Acad. Sci., XII., p. 210.

thus formed never have the sharp, angular outline that they have in the case of the feldspar. Irregular tongues of the aggregate eat their way into the quartz, gradually spreading, cutting across, and separating grains originally continuous, and finally entirely replacing them. Such complete replacement of the quartz is, however, exceptional, and seldom extends through any considerable mass of the rock. Although the quartz usually lags behind the feldspar in the process of alteration, the degree of change in the two minerals has no constant relation. For, on the one hand, a section whose feldspar is completely replaced by the aggregate may retain most of its original quartz, while, on the other hand, a section with quite fresh feldspar may show much alteration in the quartz. Not uncommonly the alteration proceeds most rapidly along the contact between the quartz and feldspar. It is hardly probable that this results from chemical causes; it must, rather, be due to the more ready circulation of solutions along these contacts. This may, perhaps, be accounted for by a tendency for quartz and feldspar to separate under mechanical strains.

The extreme result of the alteration is a mass of the greenish aggregate with no trace of either quartz or feldspar. But more commonly the rock consists of the green aggregate with a greater or less number of quartz grains.

Under low powers the aggregate has a felt-like appearance, and a green or yellowish color. With crossed nicols it shows aggregate polarization of varying intensity, the most thoroughly altered sections being nearly isotropic.

With higher powers the aggregate is seen to be made up of small, irregular scales, with a single pronounced cleavage. These scales are quite pleochroic in green and yellow, have a parallel extinction, and low double refraction. From these facts it is very probable that the scales consist of some member of the chlorite group, or of one of the nearly related hydrous silicates. An absolute determination of species is out of the question, and it is, moreover, probable that more than one species enter into the composition of the aggregate. Some sections show mingled

with, or replacing, the green scales, colorless scales with similar cleavage, but no pleochroism, and having strong double refraction. In this case the mineral is probably muscovite. It is much less abundant than the chloritic mineral and disappears as the alteration becomes more complete. By this it is not meant to imply that the muscovite is an essential step in the process of change, as in most cases there is no trace of it, even in the earlier stages of alteration. Other substances are present in minor quantity, and generally of undeterminable character. In many cases they are evidently the result of the alteration of the normal green aggregate by ordinary surface agents, with the production of iron oxide, carbonates, etc. Such weathering often bring out very clearly a wavelike banding in the sections, which very closely resembles flow structure. When this structure appears in a section of the most highly altered rock, composed of the very low, doubly refracting aggregate, the likeness to a section of a glassy volcanic rock is striking.

Cataclastic structure is very pronounced in most sections, when the alteration has not proceeded so far as to hide it, and there can be no doubt that the crushing played an important part in the process of change.

Chemistry of the process.—As microscopical study gives no definite information in regard to the chemical composition of the altered granite, an analysis has been made of a carefully selected sample. For this purpose a specimen was chosen representing the extreme result of the process of alteration, being nearly free from quartz, with a deep green color and waxy lustre. A thin section cut from the specimen shows a mingling of green and yellow aggregates, with no trace of feldspar or quartz. The results of the analysis are shown in column I. No analysis has been made of the fresher granite, because even the best specimens are so much altered that the results obtained would give no clearer idea of the original composition of the rock than can be gathered from a consideration of its mineralogical composition.

	I.	II.	III.	IV.
SiO_2	29.70	26.88	29.45	46.90
Al_2O_3	17.03	17.52	18.25	35.73
Fe_2O_3	—[1]	—	8.17	—[1]
FeO	27.15	29.76	15.12	2.48
MgO	10.66	13.84	15.32	0.83
CaO	1.68	—	0.45	0.45
Na_2O	0.56	—	—	0.48
K_2O	0.10	—	—	6.41
H_2O	11.79	11.33	12.57	5.00
	98.63	99.33	99.33	98.88

I. Greatly altered granite, Old Sterling mine.
II. Prochlorite, St. Christophe.[2]
III. Delessite, Zwickau.[3]
IV. Alteration product of doubtful origin (probably derived from granite), Caledonia mine.

It has been shown that the original rock was an acid granite, consisting almost wholly of orthoclase, microcline and quartz, with no ferromagnesian constituents. From this there can be no doubt that it contained not less than 70 per cent. of silica, with a large content of alumina and alkalies, and little iron, magnesia, and lime. The analysis shows that the process of alteration consisted of a decided decrease in the percentage of silica and alkalies, with an equally marked increase of iron and magnesia, and the addition of much water. Moreover, this has not been a mere removal of some constituents, leaving relatively increased proportions of the others, but, on the contrary, there has been an actual addition of material from a foreign source. It is hardly necessary to say that the composition of this alteration product is totally unlike that of the product that would result from the alteration of such a granite under ordinary conditions. Of course the analysis represents, as already stated, the extreme result of alteration, but it is not probable that the results would

[1] The iron in I. and IV. is all calculated as ferrous, but there can be no doubt that some of it is in the ferric condition.

[2] Dana's System of Mineralogy, p. 654.

[3] *Ibid.*, p. 660.

be very different for an average sample. The silica uldoʍ be increased by the grains of quartz, but would hardly exceed 40 to 50 per cent.

The results of the analysis and of the microscopical study bring into question the propriety of applying to the rock the name serpentine. Modern usage seems to justify the use of the designation "serpentine" for rocks composed largely of the mineral serpentine. But the analysis of the green aggregate composing the larger part of the rock under discussion shows a composition so different from that of serpentine, that there can be no doubt of the impropriety of applying this name to the rock. Analyses of different portions of the green aggregate would probably yield decidedly different results, so that it seems useless to attempt to identify it as a whole with any mineral species; but the analysis given, as well as the optical properties, indicates a much closer relationship with the chlorites than with serpentine. This relationship is illustrated by analysis II. and III., which are very similar to I., the difference being no greater than would naturally result from the variability in the composition of the minerals concerned.

Cause of the alteration.—In endeavoring to ascertain the cause which has led to such a complete change in the granite, it is evident that search must be made among the class of processes to which Roth[1] gives the name of "complicated weathering." For the alteration is not of a kind that could be produced by the simple agents of the normal weathering of rocks, nor do the facts indicate that it is a result of ordinary dynamic metamorphism, though, as stated above, crushing of the rock has been an important factor. The granite must have been attacked by some powerful chemical agent, whose action was not general, but, on the contrary, limited to this particular locality, and to such others as show analogous alteration products. A clue to the nature of the agent is afforded by the composition of the alteration product, and by the character of the associated rocks. From the analysis it is clear that the alteration has been brought about

[1] J. ROTH, Allgemeine und Chemische Geologie, Vol. I., p. 2.

by the removal of certain constituents of the granite, and the addition of a great amount of iron, with less magnesia and much water. The association of the altered granite with iron ore, suggests that the latter is in some way connected with the process of alteration. That such a connection does exist is shown by the fact that rocks similar to the altered granite, and sometimes of like origin, occur at all of the ore mines of this vicinity; while, on the other hand, nothing of the kind is found away from the ore, although granite is a very common rock.

Accepting the connection between the alteration of the granite and the presence of the iron ores, two hypotheses are suggested to account for the phenomena. The discussion of these two hypotheses involves the whole question of the origin of the iron ores, which is considered at some length in the report to which reference has been made. For present pur poses only a very brief summary of the most salient points is necessary.

According to one hypothesis the granite is younger than, and has been intruded into, the iron ore. As a result of this intrusion the granite has undergone marked endomorphic changes, during, and subsequent to, the intrusion, becoming heavily charged with iron and assuming its present form. But this hypothesis is rendered doubtful (aside from its inherent weakness) by the absence of any contact phenomena in the iron ore, and by the presence of an analogous serpentine-like rock at another ore mine, which is derived from a finely laminated gneiss, instead of a granite. In fact, there is nothing to indicate that the change in the granite associated with iron ore is, in any way, the result of the action of heated solutions generated at the time of intrusion, while much evidence is at hand to prove that this is not the case. There is more probability in a modification of this hypothesis, by which it is assumed that the ore was originally siderite and that oxidizing meteoric waters changed it to the peroxide, with the production of much carbon dioxide, which, being carried in the percolating waters, might be a sufficiently powerful agent to bring about the alteration of the granite. This

explanation would account for the alteration of gneiss as well as of granite, but does not remove the difficulty afforded by the lack of metamorphism in the iron ore at the Sterling mine. There are, moreover, other facts which need not be discussed here, indicating that the ore is probably a secondary concentration younger than the granite. Upon this supposition is based the second, and, in the writer's opinion, more probable hypothesis to account for the alteration of the granite.

This hypothesis assumes that at the time of the granitic intrusion the ore had not been formed, its present place being occupied by other rocks, chiefly limestone. The ore was formed by the gradual replacement of the limestone, through the agency of solutions which at the same time produced the alteration of the granite. This explanation requires that a source shall be found for the solutions supposed to bring about the whole series of changes. It is believed that such a source exists in a ridge of gneiss which rises a few rods west of the mine. The rock of this ridge is highly pyritiferous and contains also much magnetite. As the result of weathering, the surface becomes rusty, and the pyrite almost wholly disappears, leaving the rock light and porous. While this pyritiferous rock is not shown directly at the mine, there can be no doubt of its presence, as its strike is such as to carry it very close to the ore body.

The oxidation of the pyrite yields solutions containing iron sulphates and sulphuric acid. These solutions must be capable of producing very marked chemical effects, and are just the sort of agent required to account for all the phenomena under consideration. Working down the dip and coming in contact with limestone and granite, they would change the former to an iron ore, with the consequent formation of solutions of lime and magnesia sulphates. These solutions, as well as those derived directly from the pyrite, would attack the granite, and, being very different from the common agents of alteration, the product of their action would naturally be of an unusual character, as is the case with the rock under consideration. The solutions would have much more powerful chemical action than the ordinary agents of

weathering and would supply the elements which, as analysis shows, have been added to the rocks.

While it is impossible to trace this process with precision, and there is no positive proof that it is what has actually occurred, still the explanation has much to commend it. It accounts for the association of the altered granite with the ore, and its absence elsewhere in the region, by assigning the alteration of the granite and the formation of the ore to a common cause. It explains the very unusual character of the alteration as the result of an unusual agent. Evidence of a general nature bearing in the same direction is afforded by the fact, stated by Roth,[1] that several of the hydrated silicates of iron and magnesia, to which the green aggregate of the altered granite is quite similar, are formed where the products of the weathering of pyrite act upon silicates. These facts seem sufficient to warrant the tentative acceptance of the hypothesis as a reasonable explanation of the phenomena observed.

Similar rocks elsewhere in the region.— As previously stated, the ore at all the mines of the region is associated with rocks more or less similar to that at the Old Sterling, and generally called serpentine. That these rocks have been subjected to a process of alteration analogous to that of the granite has already been suggested as probable, but it has not been found possible always to determine their original character. At the Dixon mine the "serpentine" is plainly an altered granite, like that of the Old Sterling. The "serpentine" at the Clark and Pike mines is an altered gneiss, but at the Caledonia mines its nature is somewhat uncertain. Here it is an aphanitic mass showing, as a rule, no trace of its original minerals or structure. By Shepard[2] it was included in his mineral species Dysyntribite, whose variable nature was afterwards shown by Smith and Brush.[3] Its relation to the ore is such as to suggest an intrusion, but the

[1] J. Roth, Allgemeine und Chemische Geologie, Vol. I., p. 238.

[2] R. U. Shepard, Am. Jour. Sci. (2) XII., p. 209. Treatise on Mineralogy, p. 146.

[3] J. L. Smith and G. J. Brush, Am. Jour. Sci. (2) XVI., p. 50.

data are scanty and unreliable. The composition of the rock, shown in IV., is so different from that of the Old Sterling rock, as to raise some doubt of a unity of origin. This is particularly true when it is considered that the Caledonia rock, if derived from a granite, has generally lost all trace of its quartz, and yet has suffered less chemical change than has the Old Sterling rock, in which much quartz still remains. This fact might, however, be accounted for by some difference in the solutions causing the alteration, or by a more complete crushing of the granite. The latter explanation is particularly probable, as the granite of the region not uncommonly runs over into very fine granulitic phases. There are, moreover, very pronounced indications of crushing and shearing in the rock of this locality. Some specimens of the rock, however, contain quartz, and in thin sections closely resemble the Old Sterling specimens. Examination of these sections makes it difficult to avoid the conclusion that the Caledonia "serpentine" is also an altered granite. The microscopical evidence in favor of such a conclusion is very strong, though not affording, as in the case of the Sterling rock, a complete demonstration.

From the facts at hand it may be stated that the so-called serpentine of the various mines is derived from different rocks, whose character must be determined in each case. There is nothing to indicate that the original rock was, in any instance, a basic intrusion, but, on the contrary, where it has been found, it is decidedly acid. Moreover, the alteration products are not sufficiently uniform in character to be grouped under a specific name, and, even were this done, the term serpentine, which has always been applied to them, would have to be supplanted by something more in accord with their composition.

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